

EDITORIAL COMMENT

Stenotic Aortic Valve Area

Should it Be Calculated From CT Instead of Echocardiographic Data?*



Frank A. Flachskampf, MD, PhD

In aortic stenosis, the aortic valve area (AVA) is intuitively the most appealing measure of severity because it is supposed to be (largely) independent of stroke volume and left ventricular pump function and reflects most closely “stenosis.” Calculation of the AVA by the continuity equation is routinely performed in echocardiography (1), using 3 measurements: the velocity-time integral of the flow velocity in the left ventricular outflow tract (VTI_{LVOT}) (measured by pulsed-wave Doppler), the velocity-time integral of the flow velocity across the valve stenosis (VTI_{AS}) (measured by continuous-wave Doppler), and the cross-sectional area of the LVOT (A_{LVOT}) (calculated *at the level of the aortic annulus* from the diameter of the aortic annulus, assuming a circular geometry). The AVA then is equal to $A_{LVOT} \cdot VTI_{LVOT}/VTI_{AS}$. Because it is derived from 3 measurements, estimation of the AVA is less reliable than, for example, measurement of the peak and mean trans-aortic gradient. Nevertheless, “continuity area” calculation is regarded as a fundamental part of the echocardiographic examination of aortic stenosis. Over the past years, however, 2 observations have challenged the accuracy of this measurement:

1. A substantial fraction of patients with an AVA $<1 \text{ cm}^2$, implying severe aortic stenosis, has mean transaortic gradients $<40 \text{ mm Hg}$ despite a preserved ejection fraction (“paradoxical” low-gradient severe aortic stenosis). This subgroup of aortic stenosis patients (2,3) is clearly heterogeneous, and small left ventricular volumes, concentric left ventricular hypertrophy, concomitant mitral regurgitation, and low-normal left ventricular ejection

fraction and/or reduced “longitudinal function” have all been identified as possible contributing factors leading to low stroke volume despite a preserved ejection fraction. On the other hand, the accuracy of the continuity AVA in these patients has been questioned, implying a tendency of systematic underestimation of the AVA by echocardiography (3,4). Hence, “paradoxical” low-gradient severe aortic stenosis might be an artifact due to erroneous echocardiographic measurements, in particular A_{LVOT} . Also, a smaller AVA cutoff for severe stenosis of 0.8 cm^2 instead of 1 cm^2 has been suggested.

2. The widespread use of computed tomography (CT) to assess the aortic valve, aorta, and vasculature before transcatheter aortic valve replacement has revealed systematic discrepancies between echocardiographic and CT measurements of the aortic annulus (5,6). CT diameters of the aortic annulus are systematically larger than echocardiographic diameters, and the aortic annular area on CT often shows an elliptical shape of this virtual structure, for which standard 2-dimensional echocardiography cannot account because it calculates a circular area from the anteroposterior diameter. Although, in principle, this limitation can be circumvented by using 3-dimensional echocardiography, this is not practical without transesophageal echocardiography, a technique not routinely used in aortic stenosis. Moreover, these discrepancies seem to translate in clinical practice into more post-interventional paravalvular aortic regurgitation due to undersizing of the implanted prostheses if they are selected according to echocardiographic data instead of CT data (6), a complication known to impart an adverse prognosis.

Hence, both observations suggested systematic and clinically significant underestimation of aortic annulus and AVA by echocardiography.

The article by Clavel et al. (7) in this issue of *JACC* adds important new insights into this area.

*Editorials published in *JACC: Cardiovascular Imaging* reflect the views of the authors and do not necessarily represent the views of *JACC: Cardiovascular Imaging* or the American College of Cardiology.

From Uppsala Universitet, Institutionen för Medicinska Vetenskaper, Uppsala, Sweden. Dr. Flachskampf has reported that he has no relationships relevant to the contents of this paper to disclose.

The authors retrospectively analyzed data from 269 adult patients with aortic stenosis (average AVA, $0.94 \pm 0.32 \text{ cm}^2$) who underwent echocardiography and contrast CT within 3 months. Indications for CT were clinical, including uncertainty regarding the severity of aortic stenosis, assessment of the aorta and peripheral vasculature, and coronary artery disease. The study compares the AVA according to the continuity equation by using standard echocardiography and the AVA calculated by the continuity equation using CT planimetry data for the aortic annular area. Further, in one-half of the patients, CT data over the full cardiac cycle were available, and stenotic aortic orifice areas were also planimtered. Follow-up was obtained in 96% of patients with a mean duration of 2 years; however, patient management after the baseline examination was not standardized.

SEE PAGE 248

The main findings were as follows:

1. A_{LVOT} and AVA calculated by echocardiography and CT by using the continuity equation correlated quite well, with a coefficient of determination (r^2) of 0.61 for the AVA, but with a bias of $\sim 0.2 \text{ cm}^2$, resulting in a larger CT- than echocardiography-derived AVA. As expected, CT showed ellipticity of the aortic annular area (ratio of smallest and largest orthogonal diameters was <0.9 in 93%).
2. There was a similar bias when comparing echocardiography-derived AVA with AVA planimetry on CT images (however, the coefficient of determination was only 0.32).
3. Plotting AVA against mean transaortic gradients, the CT-derived AVA did not improve the fit with the expected relationship $\Delta p \sim 1/AVA^2$ compared with an echocardiography-derived AVA. In particular, further analyzing the CT-derived data, more eccentric annular areas provided a worse fit with gradients than more circular ones.
4. Regarding survival under medical therapy, an echocardiography-derived AVA of 1 cm^2 provided a similarly good prognostic cutoff as a CT-derived AVA of 1.2 cm^2 . A CT-based AVA did not result in a significant reclassification improvement of an echocardiography-based AVA with regard to survival under medical therapy.

Taken together, these data indicate that there is no inherent advantage in using the elliptic, larger, CT-derived A_{LVOT} instead of the circular, smaller, echocardiography-derived A_{LVOT} with the continuity equation to calculate the AVA. The CT-derived AVA on average was $\sim 20\%$ larger than the echocardiography-derived AVA.

How can it be that, despite a clearly smaller and falsely circular A_{LVOT} compared with CT, the echocardiography-based continuity equation AVA corresponds as well as the CT-based AVA with gradients and prognosis? On closer inspection, the echocardiographic application of the continuity equation for the calculation of the AVA contains several important simplifications. For example, the aortic annular area does not correspond to the region of interest of the pulsed-wave Doppler VT_{LVOT} measurement, which is placed more inside the left ventricle, and where the available cross section of flow is smaller than at the annulus level, especially if a septal bulge is present. Further, as color Doppler imaging of the systolic LVOT flow frequently shows, the flow profile there is not flat, but skewed to higher flow velocities (with brighter colors and often aliasing) close to the anterior septum compared with those close to the anterior mitral leaflet. These and other sources of inaccuracy in combination appear to some degree to fortuitously cancel out and ultimately seem not to affect the time-proven clinical usefulness of the method, as the data of Clavel et al. (7) now confirm. These findings also are in line with data showing that, despite substantial scatter, an echocardiography-calculated AVA and invasively calculated AVA according to the Gorlin equation are in good agreement with minimal bias (8).

Another interesting aspect of this study is the inclusion of CT planimetry data of the stenotic aortic valve orifice. Although the study cannot be considered definitive in this regard, it does document a systematically larger AVA by CT planimetry than by echocardiography, and this confirms previous reports from other researchers (9,10). It should be noted, however, that this is not entirely surprising because continuity-based AVA calculates an *effective* AVA, which by definition is smaller than an *anatomic* AVA (11).

Regarding the debate about the undersizing of transcatheter aortic prostheses due to echocardiographic measurement of the aortic valve annulus, this can be informed by the present data. Original sizing recommendations for prostheses on the basis of echocardiographic measurements may need to be revised “upward” to minimize post-interventional paraprothetic regurgitation, but there is no reason to assume that echocardiographic measurements are inherently inferior to CT measurements.

Important limitations of the study include patient selection by the presence of a clinical indication for CT. Furthermore, the 2-year follow-up primarily was analyzed and is displayed in the figures with regard to death under medical therapy; patients were censored if they underwent valve replacement. However,

the authors provide the information that the cutoffs, 1.0 cm² for echocardiography and 1.2 cm² for CT, which significantly predicted the primary endpoint, also were significant predictors of the secondary combined endpoint “death or aortic valve replacement.” The surprisingly high death rate under medical therapy of 20% within 2 years, twice as high as in other reports (12), indicates that comorbidities and other factors extraneous to aortic valve disease probably played an important role in managing these patients. Finally, measurement reproducibility for echocardiographic and CT measurements was not provided.

What practical consequences can be drawn from the study of Clavel et al. (7)? All measurements are

method dependent, and the AVA is no exception. This large and complex study provides reassurance of continued use of the standard echocardiographic method of calculating the stenotic valve area by the continuity equation and the use of the traditional cutoff value of 1 cm² for diagnosing severe aortic stenosis. If CT data are used, a higher cutoff for the AVA needs to be considered to diagnose severe aortic stenosis.

REPRINT REQUESTS AND CORRESPONDENCE: Dr. Frank A. Flachskampf, Uppsala Universitet, Akademiska Sjukhuset, Ingång 40, Plan 5, 751 85 Uppsala, Sweden. E-mail: frank.flachskampf@medsci.uu.se.

REFERENCES

1. Skjaerpe T, Hegrenaes L, Hatle L. Noninvasive estimation of valve area in patients with aortic stenosis by Doppler ultrasound and two-dimensional echocardiography. *Circulation* 1985; 72:810-8.
2. Hachicha Z, Dumesnil JG, Bogaty P, Pibarot P. Paradoxical low-flow, low-gradient severe aortic stenosis despite preserved ejection fraction is associated with higher afterload and reduced survival. *Circulation* 2007;115:2856-64.
3. Minners J, Allgeier M, Gohlke-Baerwolf C, Kienle RP, Neumann FJ, Jander N. Inconsistencies of echocardiographic criteria for the grading of aortic valve stenosis. *Eur Heart J* 2008;29:1043-8.
4. Jander N, Minners J, Holme I, et al. Outcome of patients with low-gradient “severe” aortic stenosis and preserved ejection fraction. *Circulation* 2011; 123:887-95.
5. Ng AC, van der Kley F, Delgado V, et al. Percutaneous valve-in-valve procedure for severe paravalvular regurgitation in aortic bioprosthesis. *J Am Coll Cardiol Img* 2009;2:522-3.
6. Jilaihawi H, Kashif M, Fontana G, et al. Cross-sectional computed tomographic assessment improves accuracy of aortic annular sizing for transcatheter aortic valve replacement and reduces the incidence of paravalvular aortic regurgitation. *J Am Coll Cardiol* 2012;59: 1275-86.
7. Clavel M-A, Malouf J, Messika-Zeitoun D, Araoz PA, Michelena HI, Enriquez-Sarano M. Aortic valve area calculation in aortic stenosis by CT and Doppler echocardiography. *J Am Coll Cardiol Img* 2015;8:248-57.
8. Lauten J, Rost C, Breithardt OA, et al. Invasive hemodynamic characteristics of low gradient severe aortic stenosis despite preserved ejection fraction. *J Am Coll Cardiol* 2013;61:1799-808.
9. Ropers D, Ropers U, Marwan M, et al. Comparison of dual-source computed tomography for the quantification of the aortic valve area in patients with aortic stenosis versus transthoracic echocardiography and invasive hemodynamic assessment. *Am J Cardiol* 2009;104:1561-7.
10. Larsen LH, Kofoed KF, Carstensen HG, et al. Aortic valve area assessed with 320-detector computed tomography: comparison with transthoracic echocardiography. *Int J Cardiovasc Imaging* 2014;30:165-73.
11. Flachskampf FA, Weyman AE, Guerrero JL, Thomas JD. Influence of orifice shape, size, and flow rate on effective valve area: an in vitro study. *J Am Coll Cardiol* 1990;15:1173-80.
12. Rosenhek R, Binder T, Porenta G, et al. Predictors of outcome in severe, asymptomatic aortic stenosis. *N Engl J Med* 2000;343:611-7.

KEY WORDS aortic stenosis, diagnostic method, echocardiography, multidetector CT, survival